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CHEMICAL DEFENSE COLLECTIVE PROTECTION TECHNOLOGY: VOLUME 2

Effects of Airlock Airflow Pattern, Clothing, and Exposure Concentration on Vapor Transport

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Procedures for processing personnel through chemical defense collective shelters were employed to examine the contamination of Toxic Safe Areas (TSAs), in shelters, as a result of transport of chemical agent vapor on clothing underlayers. The quantity of vapor thus transported into the TSAs was examined as a function of: airlock airflow pattern; type of outer clothing worn during exposure; and vapor exposure concentration. A simulated Survivable Collective Protection Shelter Contamination Control Area facility, at the USAF School of Aerospace Medicine (Brooks Air Force Base, Texas), was employed. Personnel—dressed either in fatigues over T-shirt and jockey shorts, or in Flyer's charcoal undercoverall (United Kingdom) over aircrew undershirt and drawers—were first exposed to chemical warfare agent simulant (methyl salicylate) vapor, and were then processed through the Liquid Hazard Area and Vapor Hazard Area. Processing included passage through either the original design airlock or a modified design airlock before entry
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chemical defense shelter processing; chemical agent simulant; mustard simulant; methyl salicylate; and oil of wintergreen.

19. ABSTRACT (Cont'd.)

into the TSA. Inside the TSA, individual subjects were isolated within sealed glass offgassing booths and the vapor offgassed from each subject over a 2-h period was measured. Data indicate that the charcoal undercoverall (UK) reduced the quantity of vapor transported into the TSA, and hence increased the protection of the individual more than did the fatigues. However, no statistical evidence of airlock differences was found. Keywords:

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* Caption is paraphrased here, for the convenience of the reader.

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CHEMICAL DEFENSE COLLECTIVE PROTECTION TECHNOLOGY: VOLUME 2

Effects of Airlock Airflow Pattern, Clothing, and Exposure Concentration on Vapor Transport

INTRODUCTION

The Chemical Defense Branch of the USAF School of Aerospace Medicine (USAFSAM) conducts continuing studies on the significance of various personnel processing factors with respect to contamination of chemical defense collective shelter areas.

Contamination of Toxic Safe Areas (TSAs) of shelters by transport (carry-through) of chemical agent vapors on clothing of entering personnel has been shown to be a major problem (2, 3). Experiments performed by the Chemical Defense Branch have focused on estimation of the potential magnitude of vapor carry-through which could be associated with different types of USAF regulation clothing assemblies. A simulation of the Survivable Collective Protection Shelter-2 Contamination Control Area (SCPS-2 CCA) design adopted by the USAF* has been employed in these investigations. This facility is described in Appendix A: "Documentation of Equipment."

The work described in this interim paper is a continuation of that in USAFSAM-TP-86-2 (1). In the previous interim paper, variations were examined in vapor transport into the TSA due to: two different clothing assemblies (fatigues plus underwear, and Flyer's charcoal undercoverall [UK] plus aircrew underwear); modification of airlock dimensions; and variation in exposure concentration. The present paper compares the same two clothing assemblies (fatigues vs. Flyer's undercoverall) over a higher range of exposure concentrations. In addition, whereas the previous publication compared a modified airlock with the original design airlock, the present report compares the same modified (shortened) airlock—further modified by the introduction of laminar airflow—with the original airlock.

SPECIFIC OBJECTIVES

Specific objectives of the experiments described in this interim report were:

1) To employ a chemical warfare (CW) agent simulant, methyl salicylate, to compare the extent of contamination of the TSA by simulant vapor transported on undergarments after personnel were exposed while wearing: a) standard military 2-piece fatigues; or, b) Flyer's charcoal undercoverall (UK).

EDITOR'S NOTE: Because USAFSAM Technical Papers 86-02 (Vol. 1) and 86-05 (Vol. 2) are interim papers which deal with the same research project, much of the connecting material in both texts is necessarily similar.

*Refer to footnote, p. 19.

2) To compare the contamination-reducing capacity of a modified SCPS-2 Design Specification airlock, which had a volume of 0.8785 m^3 (31.044 ft^3) and laminar airflow, with that of the original design airlock with a volume of 2.1848 m^3 (77.201 ft^3) and non-laminar airflow (1).*

EQUIPMENT AND PROCEDURES

Equipment

Only that equipment modified for the present experiments is described in this report section. (The simulated SCPS-2 CCA facility, vapor exposure equipment, offgassing booths, and ancillary atmospheric sampling apparatus are described in detail in Appendix A: "Documentation of Equipment.")

Airlock Modification

One of the SCPS-2 airlocks was modified as described previously (1). The length was reduced from 1.048 m (3.438 ft) to 0.416 m (1.365 ft), resulting in a volume of 0.879 m^3 (31.044 ft^3), as compared with the original volume of 2.185 m^3 (77.201 ft^3). The modified airlock is shown in Figure 1; and the original airlock in Appendix A, Figure A-2.

For the present experiments, the modified (short) airlock was further altered to incorporate a laminar flow of air. Laminar airflow was established by introduction of the inlet airstream through a rigid honeycomb of 5.08-cm (2-in.) thickness, formed of phenolic resin-impregnated paper. The honeycomb openings were roughly hexagonal in shape; pore size was approximately 1 cm x 1 cm (0.394 in. x 0.394 in.); pore wall thickness was 0.051 cm (0.020 in.); and honeycomb layer thickness was 5.08 cm (2 in.).

Clothing Assemblies

The two clothing assemblies compared are itemized in Table 1; differences between the two assemblies worn during exposure are shown above the dotted line.

Procedures

Described in Appendix B: "Documentation of Procedures," are the rationale for selection of methyl salicylate as chemical agent simulant; conditions of methyl salicylate vapor exposure; and procedures for vapor generation, vapor sampling and measurement, methyl salicylate assay, and data collection.

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* Refer also to footnote on p. 19.
NOTE: All tables are grouped at the close of text.

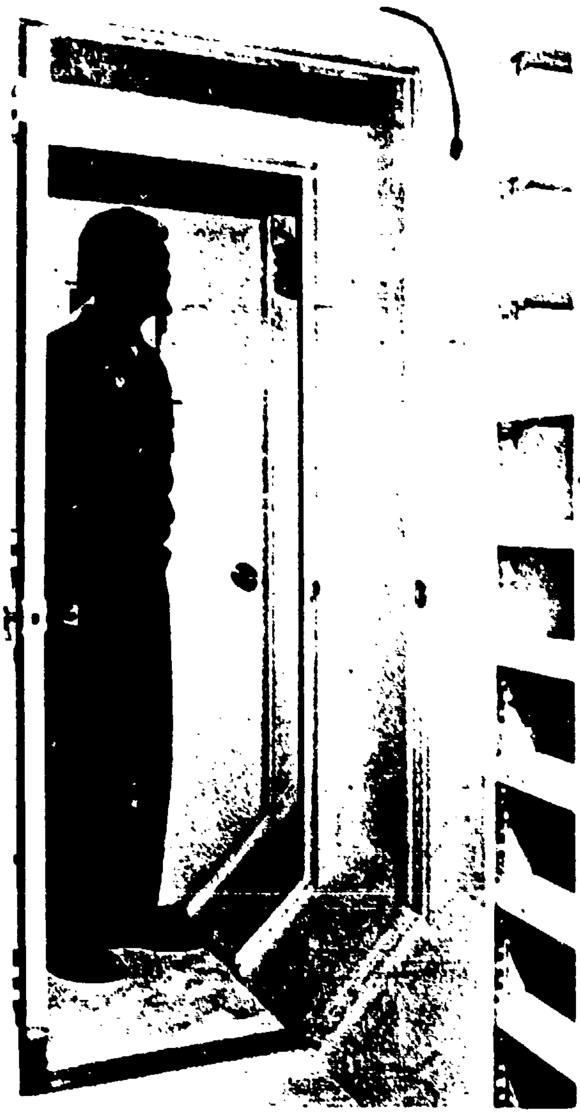


Figure 1. Modified (short) airlock with laminar airflow.

Experimental Design

The experiment was designed so that each of the participants was dressed in a particular clothing assembly (with or without the charcoal undercoverall) for two days each. Each day of the experiment an individual was in a different glass offgassing booth. The individuals in unlike clothing assemblies passed through the short or long airlock. In this manner, the influences of subject stature and booth structural variations could be maintained at a minimum. The experimental design is summarized in Table 2.

Experimental Protocol

Participants entered the vapor exposure booth simultaneously to ensure uniform exposure of all participants to the same vapor level. After a 5-min exposure to the generated vapor levels, participants exited the exposure booth, entered the Vapor Hazard Area (VHA), and removed their outer clothing. The removal of the fatigues left the participant in T-shirt and jockey shorts (Fig. 2), whereas the removal of the charcoal undercoverall (UK) left the participant in the white cotton Aircrew undershirt and white cotton Aircrew drawers (Fig. 3).

The participants passed through either the short or long airlock, spending a total of 1.5 min therein (Table 2). They then stood before the glass offgassing booth, and all entered at the same time. Ten minutes elapsed between departure from the vapor exposure booth and entry into the offgassing booths. Participants were required to spend 2 h in the offgassing booths, during which time the Sequential Impinger obtained samples of atmospheres every 15 min. Subsequent analyses of the samples were carried out as described in Appendix B. Carbon dioxide levels were determined every half-hour of the offgassing period. The total air removed from the offgassing booth through sampling was 120.8 liters.

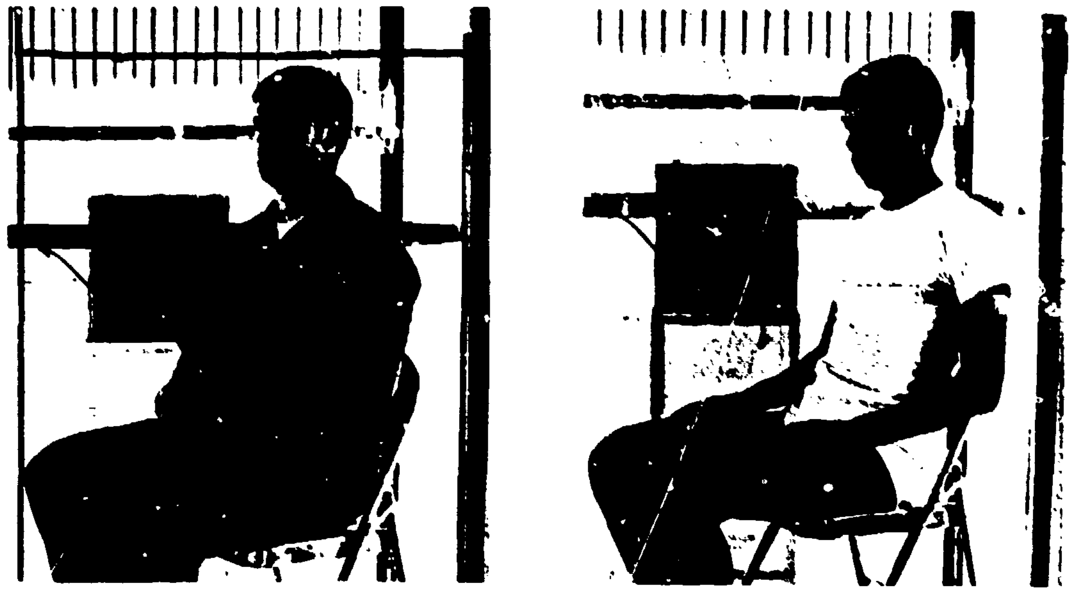
RESULTS

Methyl salicylate vapor levels in the exposure booth during exposure were measured, and these values are shown in Table 3. After individual subjects had removed the outer clothing worn during exposure and passed through an airlock into the TSA, they entered an offgassing booth where methyl salicylate vapor levels were measured every 15 min for the 2 h that the subject remained in the booth. In addition, vapor levels in each booth were measured for 1 h before the subject entered (background levels), and for 1 h after the subject exited. As a control measure, vapor levels within the TSA (at a point immediately outside the four offgassing booths) were also obtained on the same schedule as measurements within the booths.

The physical characteristics of the participants appear in Table 4.

The atmospheric vapor levels measured for each experimental day are summarized in Tables 5 - 8; values given in these Tables are raw data, uncorrected for background levels. Positions from which samples were obtained are indicated by a value of S-numerical which corresponds to positions indicated in the diagram of the SCPS-2 CCA Facility (Appendix A: Fig. A-1). Positions S-8 through S-11 correspond to offgassing booths 1 through 4. Position S-12 is the sampling point within the TSA, immediately outside the offgassing booths.

For each subject offgassed, two separate quantities were analyzed statistically: vapor concentration at the end of the 2 h in the glass booth (i.e., last 15-min sample), and maximum vapor concentration (i.e., highest 15-min sample). An adjustment for background was made by subtracting the average of the four baseline values on each day in each booth; Table 9 shows the data that were subjected to statistical analysis.



(a) (b)

Figure 2. Fatigues clothing assembly: (a) two-layer assembly worn during exposure; and (b) with outer fatigues layer removed for offgassing.

(a) (b)

Figure 3. Flyer's charcoal undercoveralls (UK) clothing assembly: (a) two-layer assembly worn during exposure; and (b) with outer charcoal layer removed for offgassing.

For last and maximum values respectively, a three-way analysis of variance (ANOVA) was performed to evaluate day (Ct), airlock, and clothing differences; and interactions of these factors. The ANOVA results are shown in Table 10. To assist with interpretation, all appropriate means examined in the ANOVA are summarized in Table 11.

For the last sample data, statistical analysis indicated significant overall difference between the fatigues mean and the charcoal mean, with fatigues having the higher vapor concentration (P=.004). Statistical evidence indicated that the magnitude of the difference was dependent on the exposure (Ct) level; i.e., no significant day (Ct) by clothing interaction. Individual t-tests comparing fatigues vs. charcoal undercoveralls on each day, generally supported the above finding that the fatigues mean was consistently higher than the charcoal undercoveralls mean (Fig. 4). The only exception was on day three, where no statistical difference was found.

For the maximum sample data, there was only borderline evidence from the ANOVA of a fatigues vs. charcoal undercoverall difference (p = .062). Even though the magnitudes of the differences between the fatigues and the charcoal undercoveralls were as large or larger than those for the previous last sample data, none of the t-tests of the differences were significant (Fig. 4). The variability of the maximum sample data was much larger. This finding, combined with the fact that sample size was small, results in a test that has very low power for detecting a difference. One data point in particular (refer to value in parentheses in Table 9) seems to be contributing to this large variance; this data point is uncharacteristically high as compared with the other charcoal suit readings.

No statistical evidence of airlock differences existed for either the maximum sample or the last sample data (Fig. 5). However, the reader is again cautioned that, because of small sample size, the test has low power.

DISCUSSION AND CONCLUSIONS

The design and physical layout of the exposure and glass offgassing booths functioned extremely well to meet the goals of the study. Use of one of the undressing booths for exposure to vapor approximates where vapor exposure begins in the SCPS-2 CCA Facility. The remainder of the facility duplicates the path that individuals entering the Toxic Safe Area (TSA) of a collective protection shelter would take. The offgassing booths, plus the sensitivity of the Sequential Impinger sampling procedure, afford an excellent experimental arrangement through which to study the vapor carried into the TSA by an individual. The paired design employed for each of the factors by the present experimental approach provides a systematic study of both mechanical and clothing vapor transfer. The surfaces of the glass offgassing booths are easily cleaned after the experiment, and have a minimum sorption of methyl salicylate as compared with offgassing cells used in past studies.

The major consideration in this study was a comparison of the two clothing assemblies. A secondary consideration was the effect of changing the airflow through the modified (short) airlock to a laminar flow, while allowing the total volume of air through the airlock and the time of occupancy to remain the same. Better protection appears to be afforded the individual by the charcoal

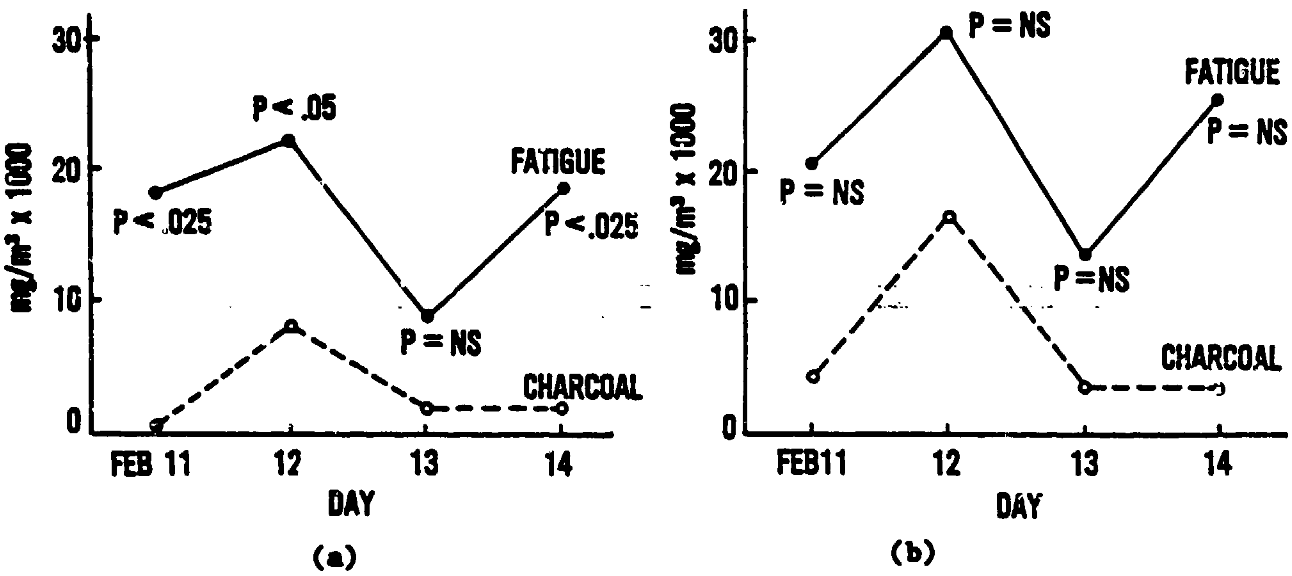


Figure 4. Mean last sample (a) and maximum sample (b) values vs. exposure concentration (Ct, indicated here as exposure day) for each clothing assembly; actual Ct values for each day are shown in Table 3. Statistical significance evaluated by t-test.

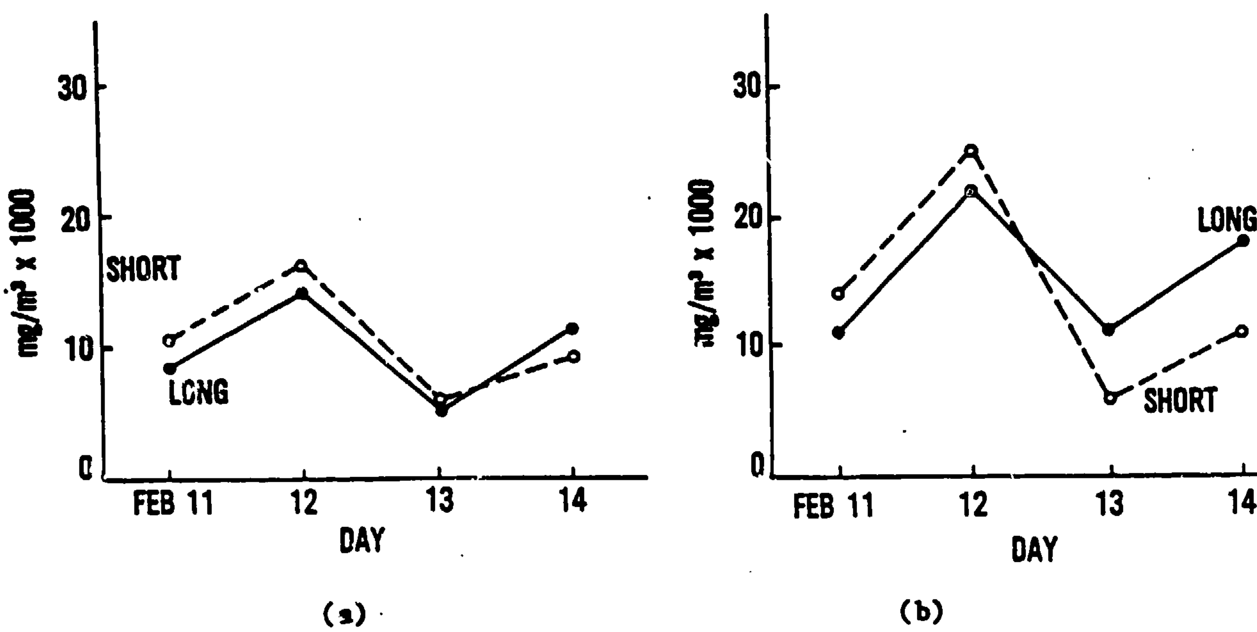


Figure 5. Mean last sample (a) and maximum sample (b) values vs. exposure concentration (Ct, indicated here as exposure day) for each airlock; actual Ct values for each day are shown in Table 3.

garment (UK) than by the fatigues. This finding could not be shown statistically with the maximum sample data, however, due to the increased variation caused chiefly by the one high charcoal observation discussed earlier. Interestingly, all of the observations obtained on day two tended to be on the high side, even though that was the day of lowest vapor exposure (Ct values in Table 3). That day was, incidentally, the same day that one of the baseline values had to be discarded as unreasonably high. Perhaps, on that day, a technical problem occurred which influenced these data.

The charcoal undercoverall (UK) will decrease the transport of chemical agent vapor into the TSA. The concept of two layers of garment has been shown to increase the safety of the individual. The charcoal-containing layer not only will provide for more rapid processing of the individual through a collective protection contaminant control area, but may possibly decrease the space required for the don/doff operation.

The simulated SCPS-2 CCA Facility can be used to evaluate various garments for the transport of chemical agent through the system, as well as the effects of procedural changes. These effects include airflow, residence time, and volume of airlocks, as related to the decrease in vapor transport through the system. Another effect which can be studied is the variation of exposure time, with the same resulting Ct. An effective analytical system has thus been developed for the study of the parameters of collective protection facilities and their associated contaminant control areas.

REFERENCES

1. Conkle, J. P., R. E. Miranda, J. R. Fischer, Jr., R. W. Page, and D. L. Bartlett. Chemical defense collective shelter technology development: Vol. 1. USAFSAM-TP-86-2, Dec 1986.

2. Crook, J. W., F. W. Oberst, and F. R. McGrath. Desorption of GB vapor from various types of clothing. Report No. 2023, AD 095141, Chemical Warfare Laboratories, Army Chemical Center, Md., Apr 1956.

3. Gilchrist, H. L. A comparative study of world war casualties from gas and other weapons. AD-E750741. Chemical Warfare School, Edgewood Arsenal [Now: Chemical Systems Laboratory (Army)], Aberdeen Proving Ground, Md. United States Government Printing Office, Washington, D.C., 1928.

TABLES 1 - 11

TABLE 1. CLOTHING ASSEMBLIES COMPARED

Fatigues	Undercoverall
Exposure	
Fatigues, std. mil., 2-pc.	Undercoverall, Flyers, UK
T-shirt (underwear)	Undershirt, Aircrew (underwear)
Jockey shorts (underwear)	Drawers, Aircrew (underwear)
- - - - - - - - - - - - -	- - - - - - - - - - - - - - -
Hood, chem. biol. (M6A2)	Hood, chem. biol. (M6A2)
Mask, CB protective (M17)	Mask, CB protective (M17)
Gloves, CP (ground crew)	Gloves, CP (ground crew)
Gloves, Insert, cotton knit	Gloves, Insert, cotton knit
Socks, tube, men's white	Socks, tube, men's white
Plastic bag over feet, socks	Plastic bag over feet, socks
Offgassing	
T-shirt (underwear)	Aircrew undershirt (underwear)
Jockey shorts (underwear)	Aircrew drawers (underwear)

CB = chem. biol.
CP = chemical protective

TABLE 2. EXPERIMENTAL DESIGN FOR COMPARING VAPOR TRANSPORT PROPERTIES OF CLOTHING

Day of exposure*	Conditions for Subject No. 1	2	3	4
1	Fatigues Airlock S Booth 1 (S8)	Undercoverall Airlock S Booth 2 (S9)	Fatigues Airlock L Booth 3 (S10)	Undercoverall Airlock L Booth 4 (S11)
2	Undercoverall Airlock L Booth 2 (S9)	Fatigues Airlock L Booth 3 (S10)	Undercoverall Airlock S Booth 4 (S11)	Fatigues Airlock S Booth 1 (S8)
3	Fatigues Airlock S Booth 3 (S10)	Undercoverall Airlock S Booth 4 (S11)	Fatigues Airlock L Booth 1 (S8)	Undercoverall Airlock L Booth 2 (S9)
4	Undercoverall Airlock L Booth 4 (S11)	Fatigues Airlock L Booth 1 (S8)	Undercoverall Airlock S Booth 2 (S9)	Fatigues Airlock S Booth 3 (S10)

* Exposure concentration (Ct) varied each experimental day.
Airlock designations: L = Long (original); and S = Short (modified).
S8 to S11: Positions from which samples were obtained. (Refer to Fig. A-1)

TABLE 3. METHYL SALICYLATE VAPOR EXPOSURE LEVELS

Day	Ct (mg min m^{-3})
1	109.21
2	79.72
3	80.27
4	130.64

TABLE 4. PHYSICAL CHARACTERISTICS OF SUBJECTS

Subject	Height		Weight	
	cm	(in.)	kg	(lb)
1	165.1	(65)	61.68	(136)
2	185.4	(73)	75.28	(166)
3	182.2	(71.75)	91.15	(201)
4	182.9	(72)	71.20	(157)

TABLE 5. METHYL SALICYLATE LEVELS FOR DAY 1 (Ct = 109.21) (mg min m^{-3})

Time (15-min increment)	Position sampled*				
	S8	S9	S10	S11	S12
1	.000	.000	.000	.004	.003
2	.000	.004	.001	.000	.000
3	.003	.000	.003	.002	.001
4	.001	.000	.000	.002	.001
5	.015	.002	.010	.001	.000
6	.006	.004	.014	.003	.000
7	.012	.001	.017	.001	.000
8	.013	.009	.018	.000	.000
9	.012	.001	.019	.001	.001
10	.019	.001	.022	.000	.000
11	.014	.004	.019	.001	.000
12	.021	.002	.018	.002	.002
13	.019	.003	.014	.001	.001
14	.013	.003	.014	.003	.039
15	.014	.003	.016	.001	.000
16	.016	.003	.014	.002	.000

*S8 to S12: Refer to Figure A-1.

TABLE 6. METHYL SALICYLATE LEVELS FOR DAY 2 (Ct = 79.72) (mg min m^{-3})

Time (15-min increment)	Position sampled*				
	S8	S9	S10	S11	S12
1	.004	.002	.002	.002	.001
2	.001	.006	.002	.005	.002
3	.008	.008	.009	.002	.003
4	.006	.008	.006	.007	.002
5	.015	.009	.019	.008	.006
6	.030	.004	.021	.005	.002
7	.038	.027	.023	.005	.001
8	.045	.029	.026	.014	.002
9	.032	.016	.025	.005	.001
10	.030	.006	.025	.005	.002
11	.031	.005	.023	.007	.001
12	.029	.014	.025	.012	.001
13	.024	.005	.018	.005	.003
14	.026	.008	.019	.004	.001
15	.028	.008	.016	.005	.002
16	.023	.007	.016	.010	.004

*S8 to S12: Refer to Figure A-1.

TABLE 7. METHYL SALICYLATE LEVELS FOR DAY 3 (Ct = 80.27) (mg min m^{-3})

Time (15-min increment)	Position sampled* S8	S9	S10	S11	S12
1	.000	.002	.000	.000	.000
2	.000	.001	.002	.000	.001
3	.003	.000	.002	.000	.000
4	.001	.001	.001	.000	.001
5	.005	.002	.003	.000	.003
6	.012	.005	.008	.003	.001
7	.002	.003	.007	.002	.155
8	.019	.004	.010	.003	.081
9	.019	.002	.009	.002	.032
10	.016	.005	.008	.002	.094
11	.018	.003	.009	.003	.003
12	.010	.002	.010	.003	.001
13	.014	.003	.008	.002	.058
14	.015	.005	.008	.002	.001
15	.013	.005	.008	.001	.003
16	.013	.003	.009	.001	.001

*S8 to S12: Refer to Figure A-1.

TABLE 8. METHYL SALICYLATE LEVELS FOR DAY 4 (Ct = 130.64) (mg min m^{-3})

Time (15-min increment)	Position sampled* S8	S9	S10	S11	S12
1	.001	.000	.002	.001	.000
2	.000	.001	.001	.000	.000
3	.001	.000	.002	.002	.000
4	.001	.004	.001	.000	.000
5	.014	.002	.010	.004	.000
6	.028	.001	.017	.001	.000
7	.032	.003	.020	.003	.000
8	.034	.001	.018	.001	.001
9	.031	.003	.019	.000	.000
10	.027	.002	.018	.002	.001
11	.026	.002	.017	.002	.001
12	.023	.005	.016	.001	.001
13	.019	.002	.013	.004	.000
14	.019	.009	.014	.002	.000
15	.017	.004	.011	.002	.000
16	.014	.001	.010	.001	.000

*S8 to S12: Refer to Figure A-1.

TABLE 9. OFFGASSED METHYL SALICYLATE VAPOR MEASUREMENTS SUBJECTED TO STATISTICAL ANALYSIS

(Values in mg m^{-3}, Corrected for background)

Day	Airlock size	Clothing	Last value	Maximum value
1	Short	Fatigues	.0200	.0200
1	Short	Charcoal	.0010	.0080
1	Long	Fatigues	.0170	.0210
1	Long	Charcoal	.0000	.0010
2	Short	Fatigues	.0242	.0402
2	Long	Charcoal	.0080	(.0230)
2	Long	Fatigues	.0202	.0212
2	Short	Charcoal	.0080	.0100
3	Long	Fatigues	.0090	.0180
3	Long	Charcoal	.0010	.0040
3	Short	Fatigues	.0088	.0088
3	Short	Charcoal	.0030	.0030
4	Long	Fatigues	.0222	.0332
4	Short	Charcoal	.0038	.0038
4	Short	Fatigues	.0145	.0185
4	Long	Charcoal	.0002	.0032

Charcoal = Flyer's charcoal undercoverall (UK).

TABLE 10. ANALYSES OF VARIANCE

Source	df	Last value			Maximum value		
		MSQ ($\times 10^4$)	F ratio	p	MSQ ($\times 10^4$)	F ratio	p
Day	3	0.6314	5.51	0.097	1.6489	1.42	0.389
Airlock	1	0.0189	0.16	0.712	0.0977	0.08	0.790
D x A	3	0.0380	0.33	0.806	0.2842	0.25	0.860
Clothing	1	7.7006	67.17	0.004	9.7656	8.44	0.062
D x C	3	0.2414	2.11	0.278	0.2689	0.23	0.869
A x C	1	0.0352	0.31	0.618	0.0002	0.00	0.992
Error	3	0.1146			1.1571		

MSQ = mean square

TABLE 11. MEAN VALUES COMPARED BY THREE-WAY ANALYSIS OF VARIANCE

Factor(s)		N	Mean: Last value	Mean: Maximum value
Day				
1		4	.0095	.0125
2		4	.0151	.0236
3		4	.0054	.0084
4		4	.0102	.0147
Airlock				
Long		8	.0097	.0156
Short		8	.0104	.0140
Clothing				
Charcoal		8	.0031	.0070
Fatigues		8	.0170	.0226
Day x Airlock				
1	Long	2	.0083	.0110
1	Short	2	.0105	.0140
2	Long	2	.0141	.0221
2	Short	2	.0161	.0251
3	Long	2	.0050	.0110
3	Short	2	.0059	.0059
4	Long	2	.0112	.0182
4	Short	2	.0091	.0111
Day x Clothing				
1	Charcoal	2	.0005	.0045
1	Fatigues	2	.0185	.0205
2	Charcoal	2	.0080	.0165
2	Fatigues	2	.0222	.0308
3	Charcoal	2	.0020	.0035
3	Fatigues	2	.0039	.0134
4	Charcoal	2	.0020	.0035
4	Fatigues	2	.0184	.0259
Airlock x Clothing				
Long	Charcoal	4	.0023	.0078
Long	Fatigues	4	.0171	.0234
Short	Charcoal	4	.0039	.0062
Short	Fatigues	4	.0169	.0219

Charcoal = Flyer's charcoal undercoverall (UK).

APPENDIX A:

DOCUMENTATION OF EQUIPMENT

APPENDIX A: DOCUMENTATION OF EQUIPMENT

SCPS-2 CCA Simulation Structure

The simulated Survivable Collective Protection Shelter Contamination Control Area (SCPS-2 CCA) facility at the USAF School of Aerospace Medicine, Brooks AFB, Texas, is diagrammed in Figure A-1. This facility is constructed of plywood, with inside walls coated with white epoxy paint to simulate the concrete structure of the operational SCPS-2 CCA units*. Internal dimensions of the simulated SCPS-2 CCA are 2.438 m (8 ft) high by 3.658 m (12 ft) wide; and each area, or section, is 2.438 m (8 ft) long. Airflow through the structure meets the operational design requirements of 1200-1800 cfm*.

The SCPS-2 CCA design provides for three stages of contamination control, with airborne contaminants being removed through entrainment by a flow of filtered air through the structure. Personnel enter SCPS-2 against the air stream into the first zone where decontamination is initiated. Within this first zone, outer clothing is: treated with fuller's earth (FE) to adsorb liquid agent or simulant; removed; and stored. Since pools or droplets of liquid agent could possibly be present, this zone is designated a "Liquid Hazard Area" (LHA). Within the LHA are 3 changing booths, approximately 1.219 m (4 ft) wide x 1.829 m (6 ft) long. Auxiliary equipment within the LHA includes trays of FE, benches, mirrors, and special racks (Fig. A-1).

Decontamination and removal of clothing and protective gear continues through the second zone of the CCA, which is a Vapor Hazard Area (VHA). After having been processed through both of these initial zones of the SCPS-2 CCA, personnel enter 1 of 4 airlocks which separate the VHA from the third zone, the TSA. In the TSA, personnel are able to dispense with the use of masks, etc., and are free to rest.

So that experiments in this facility can be monitored, sealed Plexiglas viewports are located at several points around the structure. These viewports and various sampling ports can be accessed by a raised walkway, 0.914 m (3 ft) wide, surrounding the facility.

Airlocks

Four airlocks, approximately 1.048 m by 0.856 m (3.438 ft by 2.807 ft), are positioned between the VHA and the TSA (Fig. A-1). The volume of the design specification airlock is 2.186 m^3 (77.204 ft^3)*; a photograph of this airlock is shown in Figure A-2. Air enters through louvers at the top of the cell on one side and exits through an adjustable vent near the bottom of the door on the opposite side. Under standard operational conditions, airflow is 9.905 m^3 min^{-1} (350 cfm), with a residence time of 1.5 min per subject.

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*Anderson, L., et al., Survivable collective protection shelter, SCPS-2 Design specification index drawings, X3320-16-0020 through X3320-16-71920, Systems Research Laboratories, Inc., Dayton, O., Oct 1984.

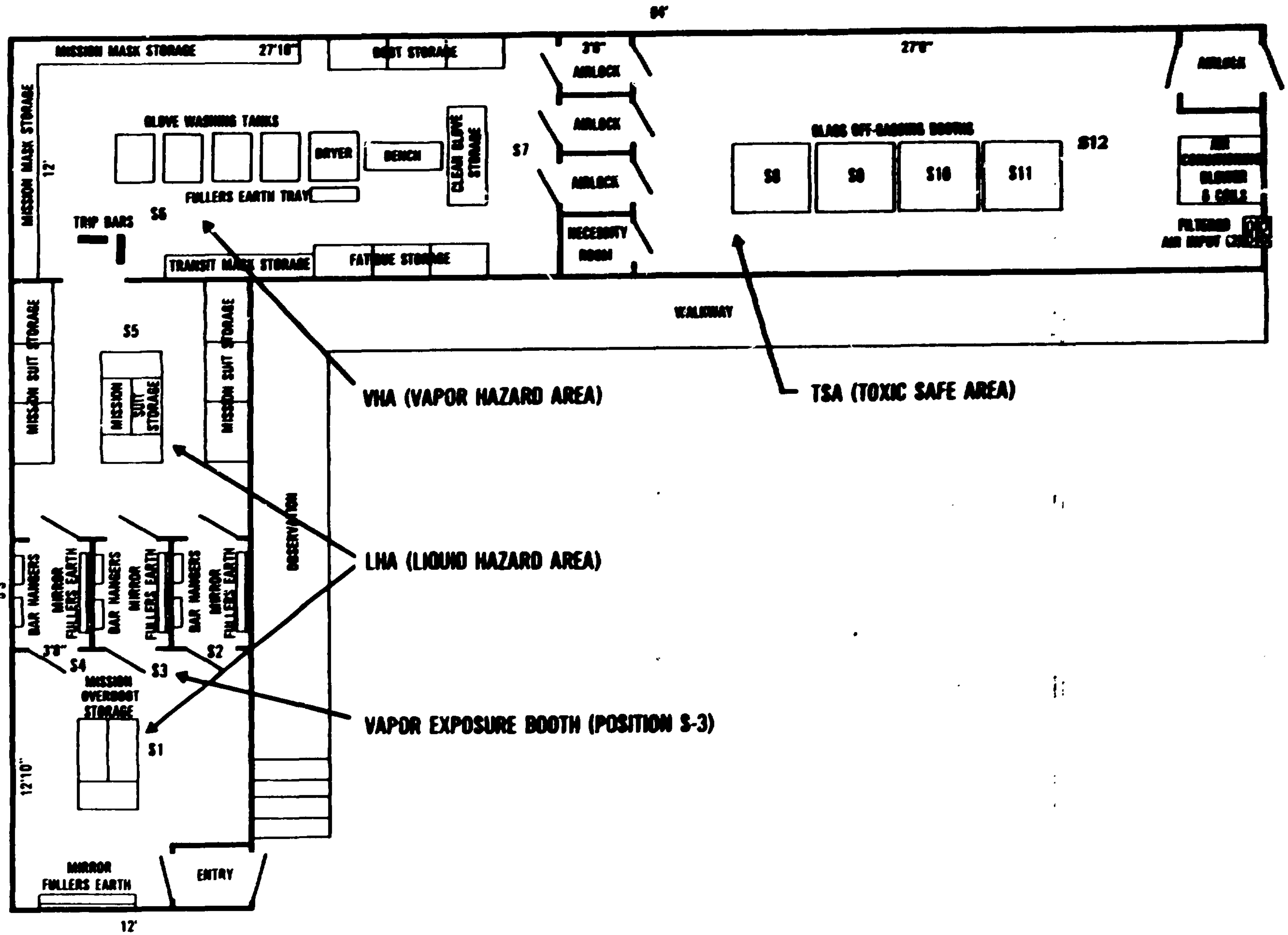

Figure A-1. Simulated survivable collective protection shelter, contamination control area (SCPS-2 CCA) facility (Brooks Air Force Base, Texas).

Figure A-2. SCPS-2 CCA Design Specification airlock [2.186 m^3 (77.204 ft^3) volume; 9.905 m^3 min^{-1} (350 cfm)]. Airflow is from louvers at top of one side to vent at bottom of opposite side.

--APPENDIX A--

Offgassing Booths

In order to collect and measure the quantity of chemical agent simulant vapor transported into the TSA by personnel under the conditions of a given experiment, four sealed booths for offgassing were designed and fabricated; several views of these booths are shown in Figures A-3 to A-5. The booths were constructed of glass, stainless steel, and chrome-plated steel, with Viton as gasket material. Dimensions of the booths were 1.194 m (3.917 ft) long by 1.054 m (3.458 ft) wide by 2.077 m (6.813 ft) high. Internal volume of the booths was calculated to be 2.613 m^3 (92.276 ft^3). Volume displacement--due to the presence of the impingers and connecting tubes, chair, or the individual who was being offgassed--was not taken into account in these calculations.

As illustrated in Figures A-3 through A-5, three sides of a booth are of glass; the other side is stainless steel, with a door 1.524 m (5 ft) high by 0.864 m (2.833 ft) wide which has a walk-in refrigerator door handle so that the door can be opened from the inside. The top of the cell has ports for 24 brass bulkhead fittings, through each of which 1/4-in. stainless steel tubing enters; each piece of this tubing is then connected to a glass impinger sampler by a 5.1-cm (2-in.) piece of Tygon tubing. Two additional sampling ports are located in the top, for an oxygen sensor and a temperature probe.

The four offgassing booths are within the TSA of the facility (Fig. A-1). Air within the TSA was sampled adjacent to the booths to detect any contamination of air outside the booths (Fig. A-1, position S-12).

Impinger Sampler

The Sequential Impinger Sampler (SIS) apparatus, developed by the USAF School of Aerospace Medicine (USAFSAM), consists of a bank of multiple impinger tubes arranged so that a timer and solenoid valve system opens a new impinger every 15 min for a sampling period of 15 min (Fig. A-5).

Impingers are obtained from Ace Glass, Inc. (25 ml, model BC779, 24/40 standard taper, with 24/40, P2479, stoppers). Orifices are re-sized to a uniform range of 7.62 - 10.16 mm (0.030 - 0.040 in.). The SIS apparatus consists of: an aluminum casing, 28 x 33 x 43 cm (11 x 13 x 17 in.); a Brailsford and Co. Model TD-1AS pump; and a Scannivalve 24-port scanning valve, Model 24C9121-433. The apparatus is powered either by a 24-V battery set, or by 100/120/220 or 230-240 VAC, from 47 to 63 Hz.

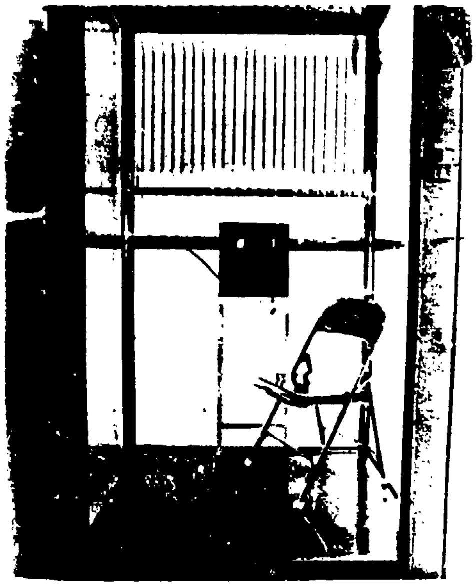

Figure A-3. Interior of glass offgassing booth.

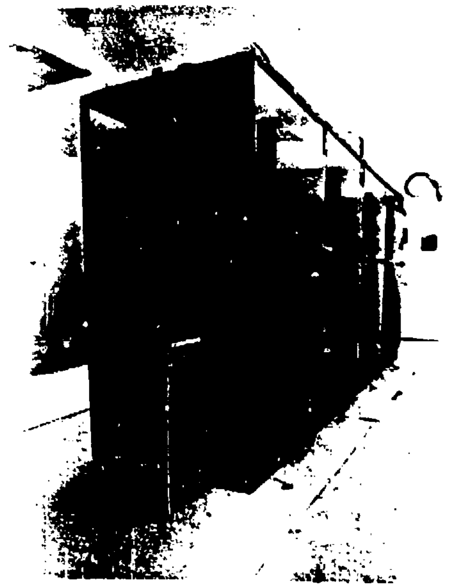

Figure A-4. Exterior of offgassing booths from entrance side.

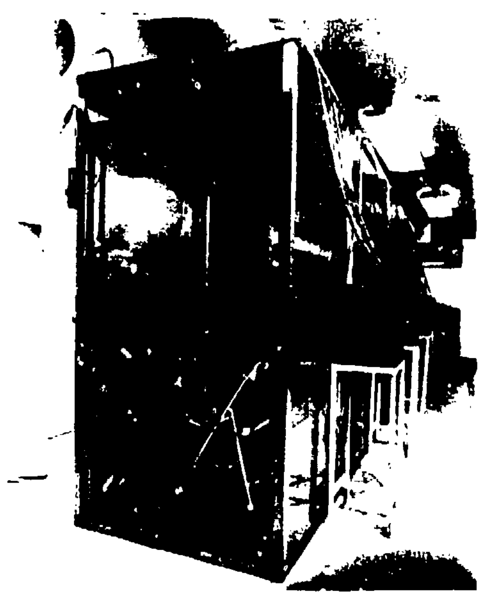

Figure A-5. Offgassing booth with sequential impinger sampling apparatus.

APPENDIX B:

DOCUMENTATION OF PROCEDURES

APPENDIX B: DOCUMENTATION OF PROCEDURES

Chemical Warfare Agent Simulant Selection

Non-toxic chemicals which possess physical properties similar to those of chemical warfare (CW) agents have been selected, and such CW agent simulants are employed in research and development concerned with SCPS-2 CCA procedures and potential modifications of design specifications. Methyl salicylate (oil of wintergreen) is used as a simulant for CW agents of intermediate volatility, particularly mustard (H)*. Relevant physical properties of methyl salicylate and several CW agents are shown in Table B-1. Methyl salicylate, which possesses an intermediate range of volatility, can be employed in either the vapor or liquid (aerosol) form. Methyl salicylate is employed as a CW agent simulant in shelter processing research conducted at the USAFSAM SCPS-2 CCA facility.

TABLE B-1. PHYSICOCHEMICAL PROPERTIES OF METHYL SALICYLATE AND SELECTED CHEMICAL WARFARE AGENTS

Property	Chemical compound					
	GB	GD	VX	HD	H	MeS[a]
Mol. Wt.	140.1	182.2	267.4	159.1	159.1	152.1
B.P. (°C)	158	198	298	217	228(dec)	220-224
Volatility (torr at 25°C)	21,000	3,500	15	1,400	630	930
Density ($g\ ml^{-1}$)	1.089	1.022	1.008	1.269	1.274	1.183
Density (vapor at 25°C)	4.83	6.28	9.22	5.4	5.5	5.24
Viscosity (Cp)	1.37	3.10	10.0	4.5	4.42	3.34

[a]methyl salicylate

GB = sarin; GD = soman; H = mustard; HD = distilled mustard;

VX = $C_2H_5P(O)(CH_3)SCH_2CH_2N[CH(CH_3)_2]2$

* Development of Candidate Chemical Simulant List: Evaluation of candidate chemical simulants which may be used in chemically hazardous operations. AFAMRL-TR-82-28. Air Force Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson AFB, Ohio 45433, May 1982.

--APPENDIX B--

Methyl salicylate, N.F. grade, is obtained from Moyco Industries (Philadelphia, Pa.).

Methyl Salicylate Vapor Exposure Conditions

For exposure to methyl salicylate vapor atmospheres under conditions of defined vapor concentration and time (Ct), a booth within the LHA is employed (Fig. A-1). All experimental subjects enter the exposure booth simultaneously to ensure uniform exposure conditions. Vapor generation is then initiated, with vapor entering the booth through a vapor-dispersal unit in the center of the ceiling. Subjects usually remain in the booth for 5 min, during which time the vapor concentration is continually increasing. Upon exiting the exposure booth, subjects enter the VHA and remove outer clothing.

Samples of exposure booth atmospheres are collected over the entire 5-min exposure period by an Impinger Sampler (Appendix A), and are subsequently assayed for methyl salicylate content (total milligrams of methyl salicylate vapor entering booth during the 5-min period); a mean quantity of methyl salicylate vapor per minute of exposure is calculated. This value is converted to milligrams of methyl salicylate per cubic meter of booth volume (mg m^{-3}), and multiplied by 5 min to arrive at an estimated value of Ct (mg min m^{-3}).

Methyl Salicylate Vapor Generation

Methyl salicylate vapor exposure atmospheres are generated by passing a stream of air over thin films of liquid methyl salicylate. The air stream containing methyl salicylate vapor is then directed through the exposure booth while subjects are present. Actual atmospheric concentrations produced within the booth over the entire exposure period are monitored.

The apparatus employed for vapor generation is shown in Figure B-1; this apparatus is immediately over the exposure booth. An airstream of 500 LPM flow rate is produced by means of a Rotron blower (Model SL 284 FG) and Fisher Porter flowmeter (Model 8204800876A6). This airstream enters a cylinder, into which one or more tubes of Vycor brand porous ("Thirsty") glass, with 40-Å pore diameter, extend through Cajon Ultra-torr S-4UT1-4 fittings, which have been modified.

These porous glass tubes contain varying quantities of methyl salicylate, depending upon the vapor concentration to be produced (Fig. B-1). The methyl salicylate migrates through the tubes, forming films of liquid on the outer surfaces. The liquid films are vaporized by the entering airstream, and the airstream containing the methyl salicylate vapor is conducted immediately into the exposure booth. The concentration of vapor in the airstream is manipulated by varying the quantity of liquid methyl salicylate within the glass tubes. Calibration curves have been determined for establishing relationships between quantity of liquid methyl salicylate in the tubes and concentration of vapor within the exposure booth.

--APPENDIX B--

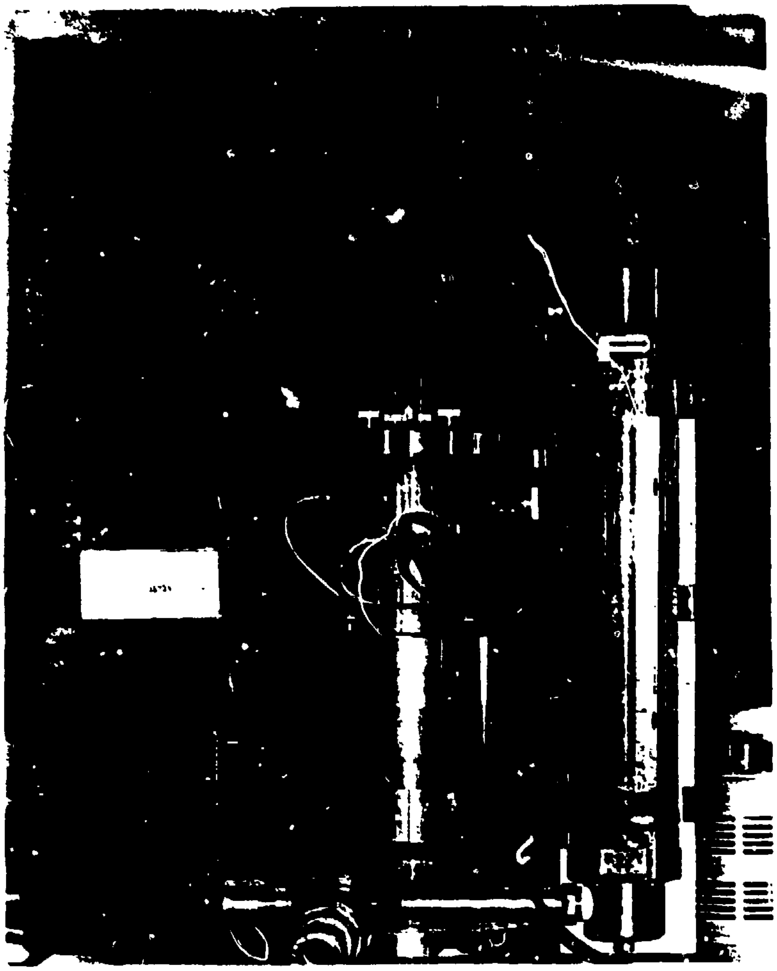

Figure B-1. Apparatus for generation of methyl salicylate vapor.

Methyl Salicylate Aerosol Exposure Conditions

Individual subjects are sprayed in open air with aerosolized methyl salicylate containing Tinopal SWN, a fluorescent laundry detergent whitener used as a marker of exposure. Tinopal SWN is obtained from Ciba-Geigy Corporation. Methyl salicylate may be employed either neat or thickened. Exposure levels are monitored by means of multiple glass microscope slides attached to subjects; the slides are subsequently removed and assayed for trapped methyl salicylate.

Methyl salicylate neat is aerosolized by a T100 sprayer with TEEJET nozzle (Model 8000067), supplied by B & G Company (Oklahoma City, Okla.). This system yields droplets of 0.3-mm mass mean diameter. Spray densities ranging from 0.5 to 10.0 g m^{-2} have been used for some methyl salicylate exposures; however, a spray density of 5.00 g m^{-2} is normally employed. The person operating the sprayer wears mask and goggles, or chemical defense mask, in order to protect his eyes from the aerosol.

--APPENDIX B--

Methyl salicylate is thickened by incorporation of Acryloid K125EA (Rohm and Haas). Thickened methyl salicylate is sprayed with a DeVilbiss JGA-502 spray gun with a P-KB-521 pressure cup and an air compressor. Reservoir pressure is 9 psi, and inlet head pressure, 90 psi. The nozzle employed is model AV-15-FF, which produces droplets of 3.0- to 6.0-mm mass mean diameter. For exposures to thickened simulant, mask voicemitters are covered to prevent staining by the Tinopal dissolved in the methyl salicylate.

Methyl Salicylate Vapor Sampling and Measurement

Samples of atmospheres present in the offgassing booths are collected by the Sequential Impinger Sampler for subsequent assay for methyl salicylate concentration. Impinger tubes contain 15 ml of a 1:1 solution of 0.1 N sodium hydroxide (NaOH) and methanol to trap methyl salicylate vapor. The tube contents are diluted to 25 ml, and are stored for 24 h to ensure completion of hydrolysis of methyl salicylate prior to fluorimetric assay of the hydrolysis products.

Methyl Salicylate Aerosol Sampling and Measurement

Aerosol exposure concentration is monitored by means of glass microscope slides attached, with tape, to the front and back of the subject (5 slides to each side). After exposure, slides are removed and placed in a slide caddy filled with NaOH-methanol solution; this solution is subsequently assayed for methyl salicylate content.

Data Collection

Results of assays of methyl salicylate content of individual SIS sample tubes are recorded for each subject by position within the SCPS-2 CCA Simulation facility (Appendix A: Fig. A-1), and by time. These data are entered into a DEC Microvax I computer for storage and subsequent analysis, employing software developed in-house for this application.

Decontamination

Decontamination procedures have been developed for use by personnel processing through the SCPS-2 CCA facility. These procedures involve: scavenging, by adsorption onto fuller's earth within the LHA, the CW agents associated with outer protective clothing and gear; cautious, programmed removal and storage of outer contaminated clothing; and passage of individual personnel through an airlock with a high, localized airflow before their entry into the TSA.

FE, a kaolin of widespread occurrence, efficiently adsorbs chemicals in liquid form. FE is composed primarily of aluminum silicates; most of the FE used at USAFSAM has been the Surrey Finest (approximately 200- to 400-mesh size), obtained from Great Britain.

--APPENDIX B--

Methyl Salicylate Assay

Samples of methyl salicylate trapped in 1:1 NaOH-methanol are allowed to stand for 24 h prior to assay in order to ensure complete hydrolysis of the methyl salicylate. Suitable dilutions of these solutions are prepared, and hydrolysis products are assayed fluorimetrically with excitation at 300 nm and emission at 405 nm. Standard solutions are prepared by dilution of known quantities of neat methyl salicylate, and these standards are assayed concomitantly with each batch of samples. A Perkin-Elmer Model LS-5 or Model 3000 Spectrofluorometer is employed. The sensitivity of this assay permits detection of 1.45 ng hydrolyzed methyl salicylate per milliliter solution, with a fluorescence yield of 0.6 units at a sensitivity setting of 2.